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RESULTS OF THE AERONAUTICAL SYSTEMS DIVISION CRITICAL PROCESS TEAM ON INTEGRATED PRODUCT DEVELOPMENT

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AERONAUTICAL SYSTEMS DIVISION
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This report provides a vision of the Integrated Product Development (IPD) Process as it could be implemented within the Aeronautical Systems Division (ASD). It captures the results of the ASD Critical Process Team on IPD and recent efforts to refine guidance for its implementation. The primary purpose of this document is to provide a conceptual framework to provoke dialogue that will lead to incremental improvements in the acquisition process. IPD is an efficient process of bringing a product from user's needs to field operation. The basic principle is to iterate and integrate the design of a product and the design of its manufacturing, operation, support and training processes with specific focus on achieving low-cost development, production, operations and support within the shortest schedule while achieving robust quality of products and services. 25) * Integrated Systems, * [illegible], * [illegible]

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FOREWORD

This document was prepared to provide a vision of the Integrated Product Development (IPD) Process as it could be implemented within the Aeronautical Systems Division (ASD). It captures the results of the ASD Critical Process Team (CPT) on IPD and recent efforts to refine guidance for its implementation. The primary purpose of this document is to provide a conceptual framework to provoke dialogue that will lead to incremental improvements in the acquisition process.

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EXECUTIVE SUMMARY

Integrated Product Development (IPD) is an efficient process of bringing a product from user's needs to field operation. The basic principle is to iterate and integrate the design of a product and the design of its manufacturing, operation, support and training processes with specific focus on achieving low-cost development, production, operations and support within the shortest schedule while achieving robust quality of the products and services. The IPD approach requires the simultaneous and integrated development and qualification of all the elements of a total system as contrasted to a sequential development process. It focuses on establishing Integrated Product Teams at the "doing level" to ensure that all functional and special interest groups are "integral contributors" rather than "monitors" in the process. For IPD to be successful, the development process must change what people do, and when they do it, so that they actively participate by creating products that incrementally define the total system. IPD increases the focus on, and "ownership" of, the products and processes, improves horizontal communications, establishes clear lines of responsibility, delegates authority, establishes clear interfaces with industry, and changes the acquisition process expectations so that the activities and success criteria are based on the total product including its manufacturing, support and training.

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1.0 BACKGROUND

The benefits of Integrated Product Development (IPD) have been convincingly demonstrated in many commercial applications.[1] Aerospace industry has also been changing and significant progress has already been demonstrated.[2] Since implementation of IPD will take place principally in industry, the best mechanisms for helping industry are to remove the inhibitors in the acquisition process and to provide leadership in accelerating the adoption and advancement of IPD practices and methodologies.[3] In fact, the aerospace industry has stated that the government must change the acquisition process for them to be totally successful.

Dr Robert Costello, while DOD Undersecretary of Defense for Acquisition, recognized the importance and potential of the IPD concepts to DOD acquisitions and required the services to begin implementation.[4] Also recognizing the significance of the concept, former ASD Commander, Lt Gen Loh, established a Critical Process Team (CPT) on IPD as a Total Quality initiative to create a culture to integrate the IPD concepts into the acquisition process.[5] The team was tasked to define and recommend: (1) integrated development and integrated management processes for the concurrent design and verification of products and their manufacturing and support processes; (2) a process for improving technology transition as it relates to IPD; and (3) incentives for industry to embrace IPD.

This document captures the results of the CPT and recent efforts to refine guidelines for its implementation. It is not a description of the as-is process but a vision of the to-be process described at an intermediate level of detail. Its primary purpose is to provide a conceptual framework to provoke dialogue that will lead to incremental improvements to our way of doing business.

Significant contributions were made by industry in identifying barriers in the acquisition process and in making recommendations for improvement.[6]

2.0 INTRODUCTION

By pursuing an approach to systems acquisition called "Integrated Product Development (IPD)", it is possible to increase the quality of our products and services, reduce costs, and decrease the time it takes to get new systems in the hands of Air Force operational users. The basic concept of IPD is to move towards a more fully integrated development approach as shown in Figure 1. For this to be successful, IPD must change what people do, and when they do it, so that they actively participate in defining and developing the total product including its manufacturing, training and support requirements and capabilities. Such objectives are not new, but have in some cases been pursued in a piecemeal fashion by functional and specialty ("stovepipe") organizations who compete with one another for resources, top-management "emphasis" and recognition. This should be recognized as the advocacy approach. While sometimes achieving success in targeted areas, IPD will enhance our chance for success of realizing the potential for improvement in performance, life and support characteristics, reduced life-cycle cost, and decreased development time. We will strive to achieve these objectives simultaneously by integrating the diverse specialty functions and the people associated with them into a unified development process. This approach places increasing emphasis on true teamwork.

IPD brings people representing different functions together at the beginning of development to work as equals in a climate of trust and ownership to incrementally and simultaneously refine the definition of the total product includ-

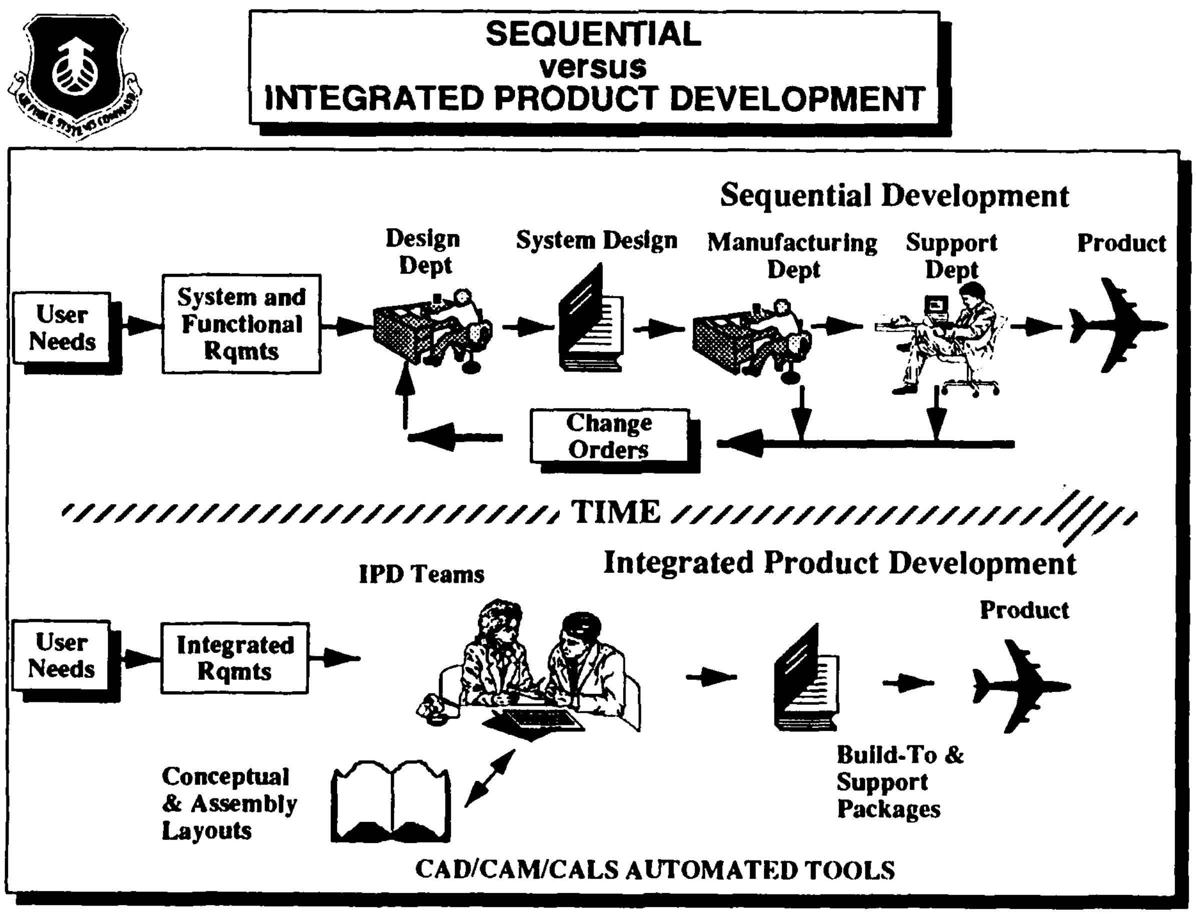

Figure 1

ing its manufacturing, training and support capabilities. Figure 2 depicts a functional architecture for this process. This process is governed by an enhanced product definition and control effort and an integrated product and process development effort. Each of these enabling efforts are described in subsequent paragraphs. These efforts are supported by enabling computer technologies that permit the use of digital data, shared common data bases, 3D-solid modeling, computerized mock-up equivalents, etc., to reduce design and fabrication times, promote product and process optimization, and improve the quality of product definition, manufacturing, training and support data. This is inherently a more efficient and responsive process.

The IPD process will facilitate the management of change and help the integrated product teams solve the customers' needs by permitting requirements, technologies and product development to co-evolve. IPD can help customers understand the subtleties of their needs and the limits of technology by making product development a problem-solving process among multiple customers and multiple functional experts working as a team.

End-users involvement throughout the process is crucial. As the more detailed definition of the requirements evolve to the design level, interpretation and selection of design specifics among alternatives is of paramount importance to the end user's eventual satisfaction. Thus, the team must be availed to the user's desire of choice and priority of operation throughout the development cycle. Without the user's involvement, the delivered system may not be fully

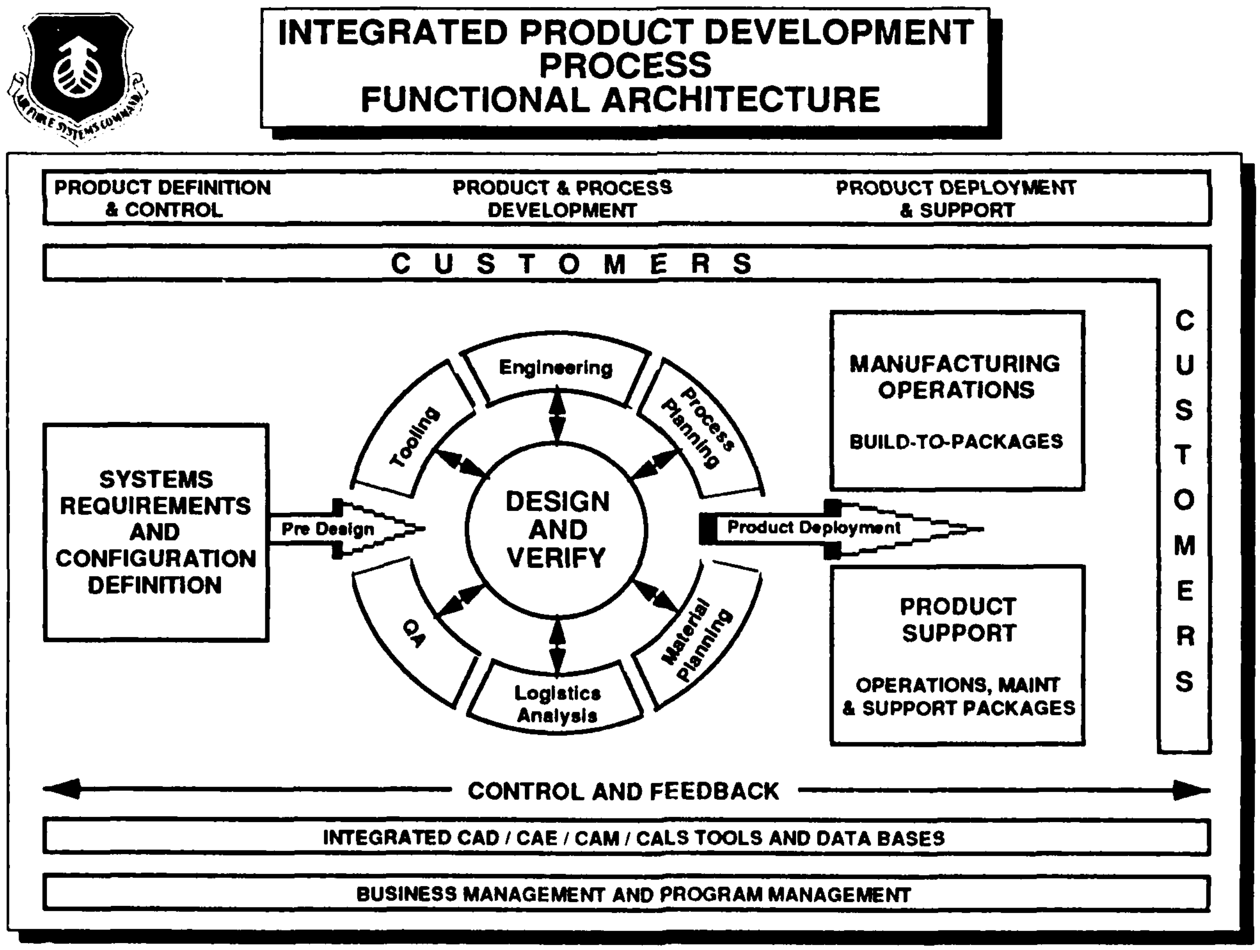

Figure 2

useful or the user may feel a lack of ownership. IPD can help resolve conflicts in meeting the needs of a wide variety of customers (operator, maintainer, supporter, trainer).

Keys to success for most development projects lie in the recognition that requirements, technology and expertise co-evolve and in the ability to balance and manage issues in a changing environment. The challenge is to meet the customers' needs for a wide range of customers who have different or conflicting requirements. These needs must be met within budget and schedule constraints, and include planning for anticipated future growth through flexible product designs, manufacturing processes and support processes.

3.0 PRODUCT DEFINITION AND CONTROL

3.1 Systems Engineering in the Acquisition Process

Systems Engineering is the function that controls the evolution of an integrated and optimally balanced system to satisfy customer needs and to provide the data and products required to support acquisition management decisions. Systems engineering encompasses the complete, integrated technical effort to define, design, produce, verify and deploy a life cycle optimized system. In the process shown in figure 3, systems engineering controls the entire technical effort to develop the total product including its manufacturing, training and support . Systems engineering addresses all "critical" characteristics of the product and its associated manufacturing, training and support in order to achieve product and process optimization. This is true from the beginning of a weapon system development; therefore, even the very early systems engineering efforts include all elements of the "team" expertise e.g. cost, design, manufacturing, support,test, etc. All members of the team work from a common baseline and trade studies address all the critical product/process characteristics of the area being studied.

The major products of this early systems engineering effort are integrated requirements, integrated specifications, interface control documents, integrated schedules and technical budgets. These products establish the "boundaries" for the efforts of "product" oriented integrated product teams (IPTs) who will continue to use the systems engineering process to accomplish the integrated product and process development activities. All members of the IPTs must embrace the systems engineering approach.

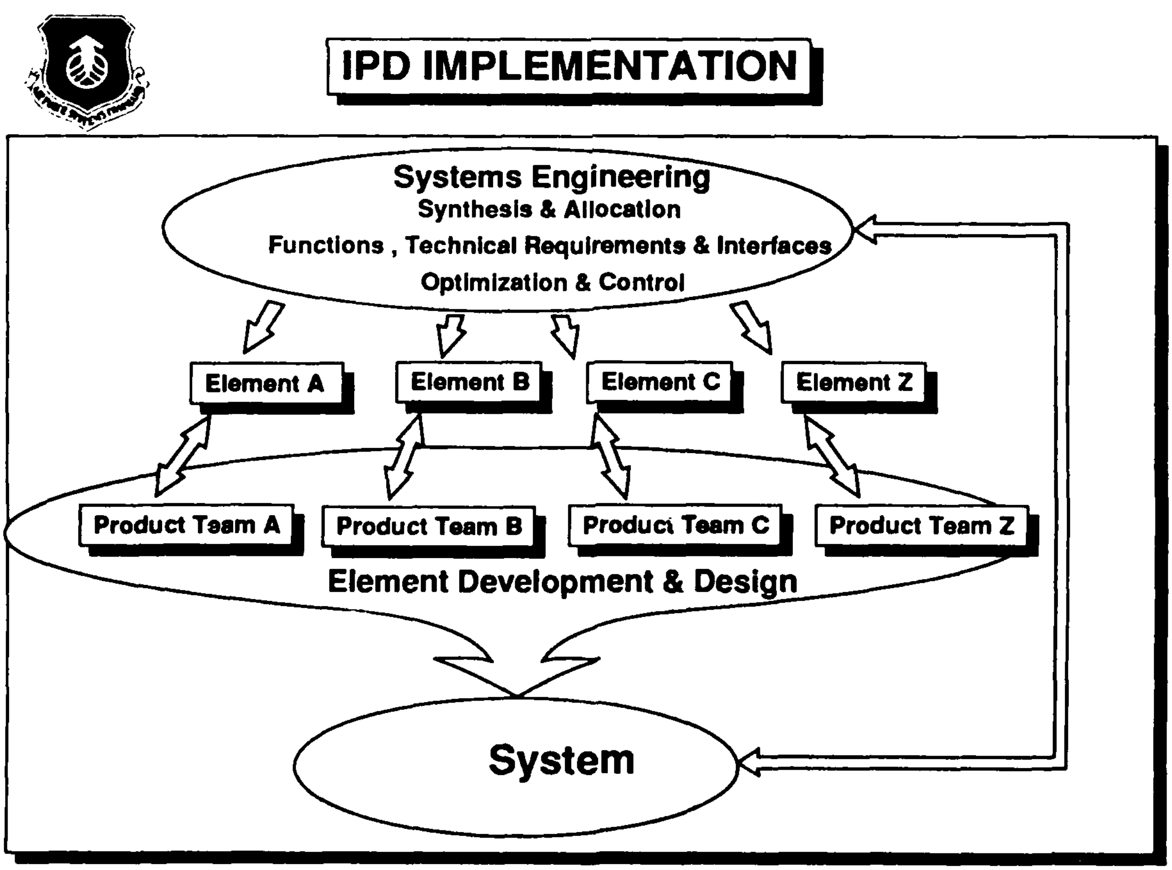

Figure 3

-- Concept Exploration Phase--

The industry's systems engineering activity during the concept exploration phase is translating the users' needs into alternative design concepts, through functional analysis, synthesis, and trade-off analysis. This is accomplished by exploring various alternatives to satisfy these needs, defining the most promising system concept(s), and developing supporting analyses and information to include identifying high risk areas and risk abatement approaches.

--Demonstration/Validation Phase--

The objectives of the Demonstration/Validation Phase are to prove that technologies and processes critical to the most promising system concept(s) are understood and attainable; and to better define the critical design characteristics and expected capabilities of the system concept(s). System level requirements are defined and refined, major system configurations are identified and analyzed, and risk abatement is pursued for subsystems, materials and manufacturing capabilities. The government product of this phase is a Systems Requirements Document. This document does not constitute selection of a specific design, but rather establishes system level requirements, employment and deployment environments and constraints and affordability constraints based on identification of feasible, affordable ranges of cost and system effectiveness. Proper identification of requirements, in performance terms, is essential to an effective acquisition strategy since real competition requires a System Requirements Document which can be met by more than one design concept. The system specification is used by the government and contractor to mutually define, from a performance perspective, the system level operational performance, capability, functional and supportability requirements and the methods for their verification. The results are documented in an offeror unique system specification based on the Air Force Guide Specification (AFGS-87253).

During the systems engineering synthesis, required configuration items (CIs) are identified. The process includes trade-off analyses to ensure that the system will satisfy the development specification performance requirements with the best possible balance of LCC, schedule, system effectiveness, manufacturability, and supportability.

Elements of the proposed system are continually assessed to identify areas of technical uncertainty that must be resolved in later program phases (risk assessment). Critical components, manufacturing processes, and training and support products should be rapidly prototyped to reduce risk. At the end of the D/V phase (or early in the Engineering and Manufacturing Development phase) agreement is reached on the system level requirements and the major configuration items are defined. The contractor develops a set of development specifications for the major configuration items. These subsystem/equipment development specifications are written using MIL-PRIME development specifications and the product integrity program specifications.[8] The MIL-PRIME specifications contain a non-contractual handbook which provides rationale, guidance, lessons learned and instruments necessary to tailor the requirements and verification sections of the MIL-PRIME specification for a specific application. As such, the system and subsystem development specifications provide the technical management framework for the Government and Contractor Integrated Product Teams.

--Engineering and Manufacturing Development Phase--

The purpose of the Engineering and Manu-

facturing Development phase is to complete all the activities necessary to go to rate production and to field and fully support the system. This is done by completing detailed design and development of the total product including manufacturing, training and support, and demonstrating that all requirements are met. The Engineering and Manufacturing Development design activity is based on development specification requirements and supporting in-process event-oriented verifications using the systems engineering master schedules (SEMS). (See Section 3.4.) Risk is continually assessed using the technical performance measurements, SEMS success criteria, and cost/schedule control system criteria. Integrated Product and Process Development activities are the primary responsibility of government and contractor integrated product teams.

Product definition and control activities focus primarily on resolving interface compatibility problems and solving technical problems discovered during development testing, manufacturing process proofing and supportability verification that cut across team boundaries. Systems engineering ensures the validation of the Build-to-Package, Training Package and Operation, Support and Maintenance Package documentation. A description of these packages are contained in Section 4.1. This includes verification of all requirements including systems safety and systems security, and completion of the subsystem/system-level verification process.

The Engineering and Manufacturing Development phase verifies operational effectiveness and suitability before deployment by testing the system or equipment in a simulation of its intended operational and support environment. Development results are reviewed to confirm that the system design meets the "exit criteria" to proceed with production, training and support activities that precede operational use. The output of Engineering and Manufacturing Development is a qualified product and verified manufacturing, training and support processes that consistently yield and maintain a quality product and the documentation necessary to enter the Production and Deployment phase. The documentation includes Build-to-Packages, Training Packages and Operation, Support and Maintenance Packages.

Integrated Product Development is a team activity involving engineering, manufacturing, test, configuration management, product support and business customers (the user, the maintainer, the trainer) that support the program manager. Achieving the desired results requires a structured process and teamwork among competent people with specific expertise and understanding of the product, users, technology base, materials, manufacturing capabilities and requirements, training capabilities and requirements, support capabilities and requirements and the acquisition process.

3.2 Translating User Needs and Establishing Integrated Requirements

A major responsibility of systems engineering is to capture the "voice of the customer" in terms that the integrated product team can understand. This is a necessary, but difficult process. One formal technique for capturing the "voice of the customer" and mapping them into product and process parameters is called Quality Function Deployment (QFD). It consists of techniques for creating and completing a series of matrices showing the association between specific features of a product and needs representing the "voice of the customer." QFD uses teamwork, creative brainstorming and extensive customer dialogue to identify customer needs and design parameters. The correlation between the needs and the design parameters is ranked and normalized. Parameters of comparable systems/subsystems are also identified and

ranked. The top-down requirements definition process continues as functions, subassemblies, parts, failure modes, critical manufacturing steps, etc. are identified and traced to critical customer needs and comparable products (or predecessor systems). Matrices are a means of recording the information to show correlations. If the customer needs are the rows of a matrix and product features are the columns, it is possible to show positive and negative correlations among the product features in a triangular table above the matrix. The triangular table above the matrix resembles a roof, hence the term "house of quality."[7] This and similar techniques have been used with reported advantages of significantly reducing changes as a design enters production and decreasing the time needed to get a design into production.

Requirements must be translated concurrently and in an integrated fashion into optimal product definitions, manufacturing processes, training processes and support processes. Systems engineering must encourage and, in fact, ensure that: (1) all requirements of the life cycle are considered and evaluated; (2) the cross-impact of various functional decisions are understood and evaluated with appropriate tradeoffs; (3) critical risks of various design options are identified and addressed early in the process;and (4) those responsible for the various functional areas participate with appropriate levels of responsibility and authority.

3.3 Integrated Specifications

DOD has given top priority to improvement in performance, capabilities and life characteristics of its systems/equipment. Its recent approach to obtaining such improvements can be called "single feature improvement." These single features are referred to as the "ilities," e.g., reliability, maintainability, producibility, supportability, etc. This "ility" approach has unfortunately led to separate advocates or specialty groups with separate budgets. This, in turn, caused "stovepipe" functional activity by the contractors as well as the government.Pursuing these single feature improvement objectives in this manner has led to a cumbersome, sequential, costly, suboptimized acquisition process.[3]

Typically, an "ility" is institutionalized through a military standard and contractually implemented through assigned tasking in the statement of work (SOW) portion of the contract. It has an associated budget and requires delivery of a product, usually a report. The MIL-Standards on which the SOW tasking is based describe generalized procedures that are similar from "ility" to "ility" and often duplicative (e.g., four deliveries of Failure Modes, Effects and Criticality Analysis). The SOW tasking generates activity that is indirectly related to the derivation of essential product characteristics.

An alternative approach is to define the product characteristics that the "ility" seeks to influence and include them in the specification. The general rule should be that, if a characteristic is important, then it should be in the specification. To be in the specification, it must be quantifiable (stated in performance terms) and verifiable. This approach ensures the appropriate top-down requirements process through the specification tree.

The growing dependence on software in today's systems poses a unique challenge to systems engineering. One of the most significant challenges in software development is software requirements definition and associated requirements change process. Development specifications will address the total system/equipment requirements including hardware and software. Achieving these total requirements is the responsibility of the integrated product team. The development of software will be accomplished from a total system perspective to address em-

bedded software, developmental test software, software for factory test equipment, support and test equipment software and training equipment software.

3.4 Performance Based Progress Criteria

The Systems Engineering Master Schedules (SEMS) provide a tailored package of tasks, schedules, and success criteria for the essential product characteristics in each of the specifications that were negotiated between the program management office and the contractor. These packages, together with the Statement of Work form the basis for the System/Subsystem Integrated Master Schedules (SIMS). The SIMS contractually identify critical development and program tasks and activities, with success criteria, that must be completed to pass identified program milestones and subsystem incremental reviews. As such, the SIMS provide the basis for developing program cost and schedules as well as performance-based progress criteria by providing meaningful measures of merit to track program progress and system operational capability for technical and business management visibility. The agendas of all program reviews and contract progress payments should be based on performance-based progress criteria identified in the SIMS.

The mutually-defined, time-phased event-driven tasks and activities contained in the SIMS and technical performance measurements provide the means for risk assessment of contractor progress. Technical performance measurement assesses product design by estimating through engineering analysis and tests the values of essential specification parameters of the current design. It forecasts the values to be achieved through the planned technical program effort, measures differences between the achieved values and those allocated to the product element, and determines the impact of these differences on system effectiveness, manufacturability and operational suitability. This technique provides the necessary management tools to put discipline into the integrated product development process by establishing accountability and ensuring management involvement.

Key top level measures of success in implementing the integrated product development process that industry [6] has found helpful are:

- Product Cost - Target cost versus current estimate (Development, Production, Operation and Support)

- Product Quality - Process performance index or first pass test yields (targets versus actual using a learning curve)

- Product Schedule - Total time versus successful completion of key tasks by major event milestones

- Implementation Costs
  - — Development hours (targets versus actuals or current estimates)
  - — Tooling costs (targets versus actuals or current estimates)
  - — Training cost per student
  - — Support cost per operational unit

3.5 Integrated Planning and Scheduling

A fundamental change to planning and scheduling is an essential part of the integrated product development process. The frequently observed practice of maintaining separate plans and schedules for each discipline is replaced by a single integrated schedule. This requires more than combining all existing functional schedules into a single document. It requires a change in scheduling. Within an overall schedule tied to a capability need date or similar milestone, schedules are event-oriented using exit criteria tied to

successful completion of development tasks and incremental product releases. The SEMS contained in the annexes to the development specifications are key building blocks of the System/ Subsystem Integrated Master Schedule.

Contractor integrated product development teams given responsibility for Development Specifications, Build-To Packages, Training Packages and Operation, Support and Maintenance Packages are responsible for developing and maintaining an integrated schedule which is "owned" by all members of the team. Schedule milestones are negotiated within the team and are the basis for performance-based progress criteria and risk management. All disciplines must assume responsibility for meeting the integrated schedule and event milestones. The focus of all members of the team is on the timely completion of the specification verification tasks and the timely release of a quality Build-To-Package, Training Package and Operation, Support and Maintenance Package. Schedules are created from a detailed understanding of the specification verification tasks, Build-To-Package content , Training Package content and Operation, Support and Maintenance Package content together with the capability and capacity of the resources required. Caution should be exercised in using historical engineering development times, manufacturing span times, training system development times and support development times in building the schedules.

3.6 Funding Profile Impacts on the Integrated Product Development Process

Money phasing is a critical element of integrated product development. Improper funding introduces major risks because it impacts the ability to keep the program in technical balance. Scheduling of technical tasks and commitments to their accomplishment by key technical milestones should be the basis for determining the funding profile. Significant program dollars could be saved with a funding profile compatible with a sound technical strategy that supports the objective of integrated product development. Funding must be made available for inclusion of all necessary disciplines early in the design process. This will change the traditional funding profile by greater up-front loading of costs. Experience shows that potential savings in development and life cycle costs more than offset the higher initial costs. The use of integrated specifications and the SIMS is intended to provide a sound basis for developing the funding profile.

4.0 INTEGRATED PRODUCT & PROCESS DEVELOPMENT

4.1 Integrated Product Development

Integrated product development will be accomplished by integrated product teams responsible for accomplishing all activities necessary to develop and qualify a complete Build-To-Package, a complete Training Package and a complete Operation Support and Maintenance Package. This activity should address as a minimum all the classical development activities including manufacturing engineering and planning and logistics engineering and planning.

Each integrated product team should function within the boundaries established by the products of system requirements and configuration definition activity.

Integrated product development requires that the engineering description of a part, assembly, etc., and the processes to build and support the product are defined simultaneously. This integrated product development is based on incremental product releases which ensure that all requirements are compatible by horizontal integration of all elements. Figure 4 shows an integrated product development process flow with incremental release products and enhanced configuration management.

The development of layouts defining the product and the processes to produce and support it are fundamental to integrated product development. Layout development is important to avoid redesign, poor quality, difficult to manufacture and support designs, and rework. The layout development process has two phases.

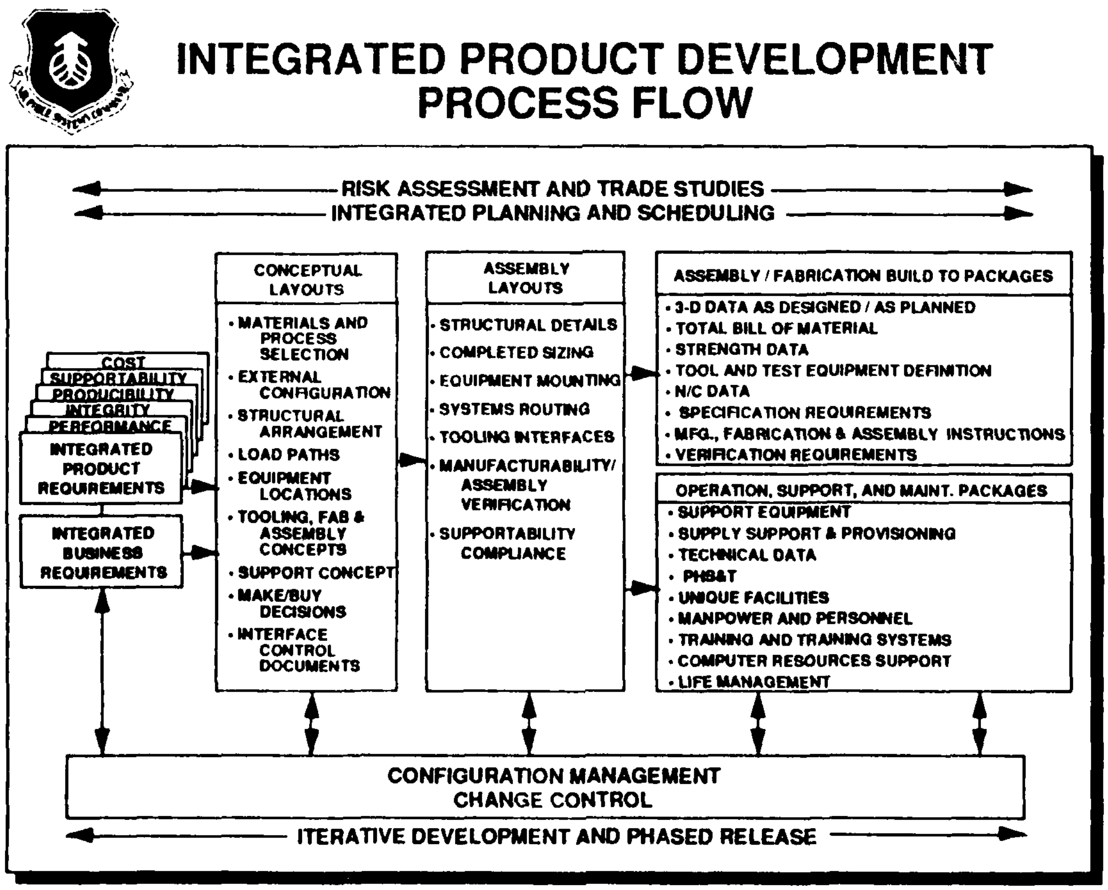

Figure 4

The first phase of layout development is defining the design, manufacturing, tooling, and support concepts. Support concepts include conceptual technical orders based on initial identification of support equipment, skills, etc. Completion and release of conceptual layouts provide the basis for make/buy decisions, generating interface control documents, and achieving a multi-disciplinary consensus on the conceptual system configuration and operating and support concepts. In the traditional process, conceptual layouts may be created but are not formally documented and controlled.

The second phase of layout development is the creation of assembly layouts. These layouts define structural joints, manufacturing splices, tooling requirements and interfaces, and have structural sizing sufficient to proceed with detailed design. The structural and systems interfaces and manufacturability, assembly and supportability elements of the design can be validated using computer graphics. Assembly layouts are also formally released and subject to configuration control. The creation and release of assembly layouts is one of the major differences between integrated product development and traditional design practices. Assembly layouts facilitate the use of automated design, design analysis, and computer integrated manufacturing and computer aided logistics tools.

In the next phase of integrated product development, detailed part and assembly Build-To-Packages are then released. These Build-To-Packages will contain all the information necessary for a manufacturer to build the required product. This requires close communications between the developer of the product and its manufacturer. Verification, whether it be performance, fit, function, tool proofing, numerical control definition, etc., is an important ingredient of the package and will be subject to configuration control.

The three-dimensional/two-dimensional (3D/2D) as designed/as planned data contains a complete geometric description and if available, a feature description, of the product. The exact form of the 3D/2D description is flexible and can, over time, adapt to anticipated changes in computer graphics technology including solids and feature based modeling. Traditionally, as-designed data was created by engineers and as-planned data was created by production planners. Under integrated product development, both must work together to create the complete product description.

The Total Bill of Material will provide the manufacturer with a single, internally consistent source of needed data. It combines the engineering bill of material and the manufacturing bill of material. As-built and as-supported information can be combined with the as-designed and as-planned data into a total bill-of-material for each part/assembly.

Strength data captures the design loads information, documents the critical features of the product, and captures all the design margins. Weight data is included for tracking actual weight performance by the manufacturing shop. The exact form of the data should be flexible and determined to a large extent by the program. The key is to achieve greater discipline in the process by bringing the loads and strength data under configuration management rules and creating a common data base for product developers and follow-on repair and engineering change activities.

Tool and test equipment definition data is essentially a Build-To-Package for the tools and test equipment required to build the detailed part or assembly covered by the overall Build-To-Package. It includes 3D/2D data, tool order, and tool and test equipment usage information. Information required to initiate long lead tool

design, fabrication, and procurement efforts (e.g., loft surfaces, tool datum planes, forging specifications) will be incrementally released. Scheduling of these incremental releases will be contained in the integrated plans and schedules.

Numerical Control Data provides a good description of a product from a manufacturers point of view. This data is provided for machining parts, routing sheet metal parts, cutting composite plies and for tooling. Traditionally, Numerical Control programming has been done by the manufacturing organization based on data provided by Design and Planning. Under the integrated product development process, this activity will be accomplished as an integral part of the Build-To-Package and tailored to the needs of the manufacturer whether it be in-house or subcontracted.

Specification requirements contain the product specifications (hardware and software), the verification/test procedures and verification results from the systems engineering process. For example, specifications and test instructions are included to validate proper operation of hydraulics, fuel, and electrical subsystems as assembled in a major component. For individual pieces of equipment, the specification requirements would typically include the procurement specification and all qualification test requirements.

Manufacturing, fabrication and assembly instructions will contain all the information required to build the part or assembly. It will contain any necessary visual aids, a complete work order and non-conformance disposition rules and data. Process instructions will contain all the information contained in process specification such as finish requirements, marking, labeling, packaging, handling, storage, and shipping requirements; Non-Destructive Inspection requirements; heat treatment, etc., which apply to the part or assembly These instructions should stand alone and the manufacturer should not refer to any information beyond the Build-To-Package. The packaging, handling, storage, and transportation (PHS&T) requirements shall be developed concurrently with PHS&T requirements for follow-on support to insure compatibility. The work order will contain the stock requirements, operations sequence planning, tool requirements, industrial engineering targets, etc. Manufacturing, fabrication and assembly instructions have traditionally been generated after the product definition was released. Under integrated product development they are included in the Build-To-Package and early estimates of this information are used to generate the schedule for Build-To-Package release.

Verification Requirements provide the means for clearly communicating the important factors for fabrication of the part/assembly from the integrated product team to the manufacturer. Any special fit, form, function, information developed will be included.

The Operations, Support and Maintenance Package should be developed in parallel with the Build-To-Package to capitalize on synergistic effects. Substantial benefits should be achieved in the areas of spares definition, diagnostics, support and test equipment, technical data, training, software support, etc. To the extent practical, the support data will utilize the data from integrated development in the form of Build-To-Packages to develop the Logistics Support Analysis Record and the provisions for life management as was qualified with the product. Definition data for products of the Operations, Support and Maintenance Package are essentially Build-To-Packages for these elements.

The integrated product development process shall accomplish all the planning necessary for Manufacturing Operations and Product Support to accomplish the Product Deployment and Support functions.

4.2 Integrated Product Design Tasks

Agreements must be reached within each IPT on the design tasks and their completion criteria. Criteria used for implementing the product design tasks within IPD is as follows:

Service life in years; design usage in terms of aircraft/platforms, mission profiles, mission mix; total operating hours in the air/on the ground; and the number/type of operating cycles for inflight operations, ground operations, off vehicle (intermediate and depot shops) will be documented. This information will be established through close coordination between the program offices, the user(s), and the contractor. It will then be used by the contractor to establish the design criteria to be included in the integrity program documentation that will be used to verify compliance with requirements.

Environmental requirements (operational, storage, transportation, etc.) will be established and used to verify functional performance throughout the environmental range.

Competitive benchmarking, logistics support analysis use studies and comparative analyses, technological opportunities, and customer needs will be used to establish and prioritize major product design requirements, constraints and improvement objectives. The best products in the field are analyzed in detail to assure that the design will be superior in all aspects.

Characteristics of material to be used in the design will be defined and worst case material characteristics that will be allowed to pass through the manufacturing and/or maintenance processes and/or process control/inspection processes will be identified. Process capabilities and process control requirements will be established using process capability studies, process modeling/analysis, parameter design and tolerance design techniques, as appropriate.

Design criteria and design margins will be established that are sufficient to achieve an acceptable design service life and stable manufacturing processes, compatible with the design requirements to minimize scrap and rework. Design criteria will also be established for assembly, testability and for maintainability to include manpower, skill levels, repair times and repair tools/equipment.

Manufacturing feasibility, design for assembly, design for maintainability, and design to cost analyses will identify the most economical means of production through individual or collective consideration of design criteria, materials selection, manufacturing techniques or processes, and repair techniques or processes. New manufacturing and repair technology requirements will be identified.

Components that meet the required service life will be identified and life limited items/components will be identified with their life limits.

Preliminary analysis of the design will be complete prior to Conceptual Layout Release and formal analyses will be performed prior to Assembly Layout Release on components of the system to evaluate their initial and residual strength, life requirements, and maintainability requirements.

Testing of materials, parts, and components will be performed to the design usage spectrum to simulate usage environment, to verify life analysis procedures, to verify allowable stress and strain levels, materials selection, etc., and to develop guidance for truncating durability tests.

Damage tolerance and durability control planning will identify and define all of the tasks necessary to ensure compliance with damage tolerance and durability requirements. This will include corrosion prevention and control, environmental protection, materials selection and

materials procurement specification requirements, manufacturing process specification requirements, critical design drawing information, and incremental verification of subsystem and equipment maintainability requirements.

One lifetime of durability testing will be completed prior to the Build-To-Package Release. This will be supported by ground test and flight survey data, as appropriate. Two lifetimes of durability testing plus a close visual inspection will be completed prior to the full rate production decision. If the economic life is reached prior to two lifetimes, testing will end and an analysis will be required to determine if production changes are required. Durability testing including development testing and qualification testing will be performed on development units that are representative of the production configuration. It will be performed on the full subsystem or on major assemblies as approved by the program office. All inspection/ diagnostic procedures and intervals used on the durability test article(s) will be the same as those scheduled for operational use.

Damage tolerance testing will demonstrate compliance with the damage tolerance design requirements for one design service life or the maintenance/failure-free operating period prior to the Build-To-Package Release. Damage tolerance testing will be flexible and tailored to specific systems. The size of the test program will depend on the number of assemblies in the test, extent of verification obtained during durability testing, and the extent of previous component tests. Detailed test requirements (type of tests, quantity, choice of specimens, damage/ fault locations, etc.) will be established by the contractor and approved by the program office. Corrective actions (e.g., design changes, special inspections or process changes) will be required for deficiencies disclosed during these tests.

Durability/damage tolerance test results along with a hardware quality audit and failure analyses/fractographic examinations will be used to demonstrate that requirements are met or the impacts resulting from deficiencies are quantified to support program decisions. A hardware quality audit and failure analyses/fractographic examination will be performed upon completion of the durability/ damage tolerance testing for the purpose of locating critical areas not previously identified; verifying life (age) limits; assessing the adequacy of inspection/diagnostic procedures and intervals; and assessing the initial quality of the equipment. The scope of the inspection, the specific inspection procedures used, and the extent of the detailed examinations will be tailored for each program.

Manufacturing processes will be proofed before the Build-to-Package Release and validated during Low Rate Initial Production (LRIP) to confirm the adequacy of the production planning, tool design, assembly procedures, work instructions, training procedures, etc. Manufacturing process proofing and validation will be done at the prime contractors, subcontractors, and key suppliers. Rapid prototyping and computer-aided visualization techniques such as animation, simulation, and rendering systems may be used to support the proofing process.

Failure investigations/analyses will be performed during design, development, qualification, and production to ensure timely identification of root causes and corrective actions, and an assessment of the effectiveness of the implemented corrective actions.

Verification compliance planning will be completed and verified prior to Build-To-Package Release, validated during LRIP, and fully implemented during full rate production. This planning will include manufacturing process controls and/or inspection requirements derived from the design criteria. Process control requirements will be established for each level of

assembly (statistical process controls, adaptive machine controls, environmental stress screening, non-destructive procedures, automated inspections, etc.) based on material characterization, manufacturing process variability and strength/durability requirements. The planning information will also cover the failure reporting/ feedback process including physics of failure analysis and disposition criteria for non-conforming material based on the failures affect on functional performance and life. Material management of critical, controlled or strategic material will be included.

Subsystem and equipment level maintainability analyses will be completed prior to Build-To-Package Release. Incremental maintainability verifications will be completed on developmental items from components to configuration items and formal maintainability demonstrations will be completed prior to the LRIP go-ahead decision. Maintainability demonstrations will be conducted in an environment which simulates, as closely as practicable, the operational and maintenance environment planned for the item. This environment will be representative of the installation conditions, working conditions, tools, support equipment, spares, facilities, and technical publications that would be required during operational service at the defined maintenance level and will be accomplished by personnel of the equivalent skill level having received the specified training.

Provisions for life management will be completed prior to the LRIP go-ahead decision, verified prior to completion of Initial Operational Test and Evaluation (IOT&E), and implemented on all fielded equipment. Life management provisions will include the expected break rates for the equipment, the time phased maintenance tasks for preventive/schedule maintenance, maintenance process controls/inspection requirements, the expected fix rates for the equipment, the process and devices for monitoring field usage and installed environments, a metho 'l-ogy for modifying break rate prediction and maintenance tasks based on changes in operational usage and installed environments, and provisions for updating the Logistics Support Analysis Record. Life management data will provide a continual assessment of the in-service integrity of the equipment; provide a basis for determining logistics and force planning requirements; and provide a basis to improve design criteria and methods of design, evaluation, and substantiation for future systems/ equipments.

This integrated design process is responsive to the objectives of integrated product and process development. Many of the elements of this process are already established in the product integrity programs.[8]

4.3 Integrated Technical Reviews

Technical reviews are an integral and essential part of IPD. Technical reviews can range from very formal reviews to very informal reviews concerned with product and/or verification elements of the development specification. All reviews share the objective of determining the technical adequacy of the existing product and process design to meet requirements.

As the acquisition program moves through the life cycle, the reviews become more detailed and definitive. Technical reviews consider all aspects of the product and process design that are relevant to the progress of a particular design phase. Contracts will require formal technical reviews that will be structured to fulfill the two main purposes of the technical review, which are: (1) to augment with additional knowledge the integrated product design and analytical activity; and (2) to evaluate accomplishment of specified design and verification tasks which need approval before proceeding to the next step

in the acquisition process.

Technical reviews are used as the process control mechanism for a program. As such, the specifications form the cornerstone. The specifications are bi-lateral agreements between industry and the government on the requirements and the process for achieving these requirements as documented in the Systems Engineering Master Schedule (SEMS). Other contractual requirements are captured in the Statement of Work. The process for meeting these requirements are combined with the SEMS to make the System/Subsystem Integrated Master Schedules (SIMS). Technical Performance Measurements are used to establish the entry and exit criteria for each requirement while the event-oriented SEMS/SIMS provide the verifiable success criteria and entry and exit criteria for the process of meeting the requirement. Using these tools readiness for formal reviews are incrementally assessed using the status as entry criteria with the formal review being the final confirmation of readiness to proceed. This process is used to create the agendas for the reviews which ultimately culminates in a series of approved products. Several key products are the system specification, development specifications, interface control documents, conceptual layouts, assembly layouts, build-to-packages, training packages and operation, support and maintenance packages. Successfully incremental completion of this process is tied to contract demonstration milestones and to progress payments.

Figure 5 shows a matrix of requirements and accomplishments tied to program milestones and system/subsystem incremental reviews. This correlation matrix can be used to help in planning for the reviews.

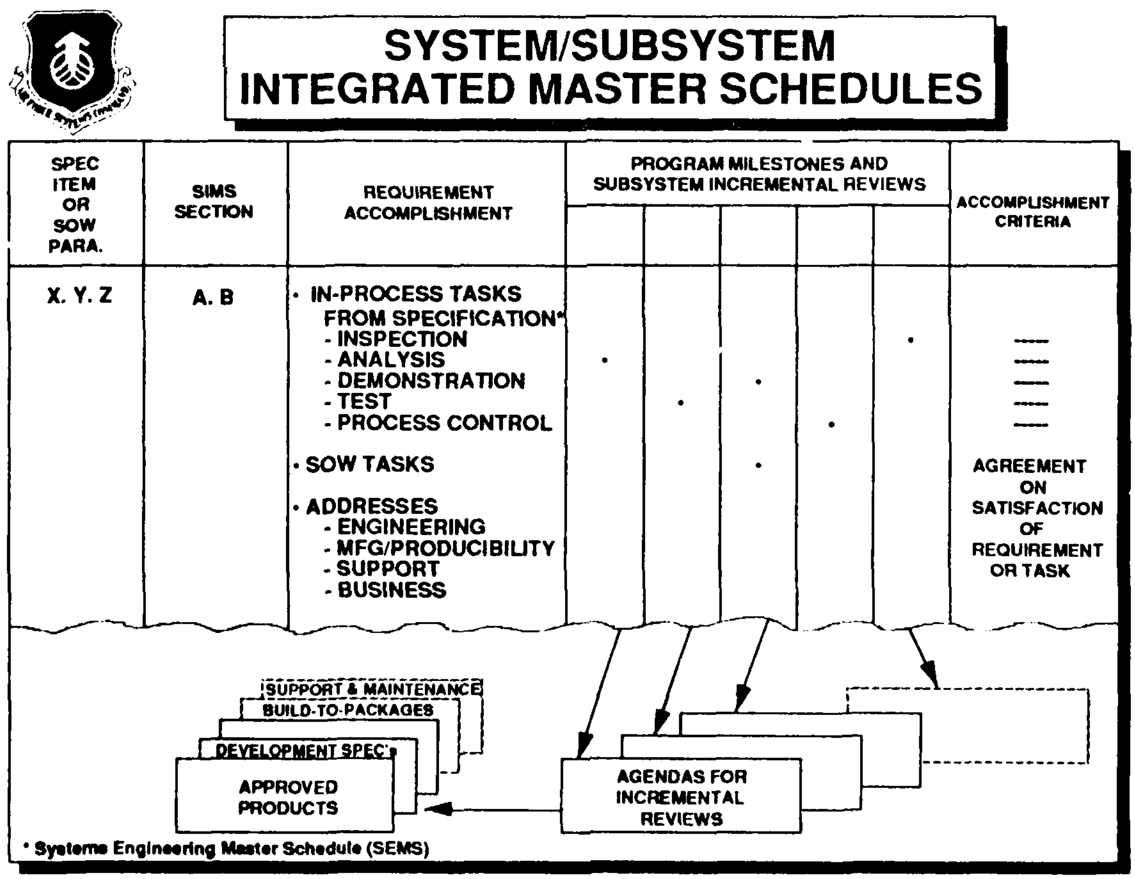

Figure 5

Technical reviews and audits focus on the total product including its manufacturing, support and training. As such, software, logistics, test and production process reviews are an integral part of each su stem's incremental review. Figure 6 shows a series of formal reviews that reflect an integrated approach within an IPD framework. This approach reflects early baselining of performance requirements and configuration definition data while deferring government configuration control of the detailed build-to information. Technical reviews and audits culminate with the validation of the Build-To-Packages and the Operation, Support and Maintenance Package (including the Training Package) with the as-built/produced products and DT&E/IOT&E and Factory Tests. Incremental approval of the key products establish the baseline for configuration management.

INTEGRATED TECHNICAL REVIEWS & AUDITS

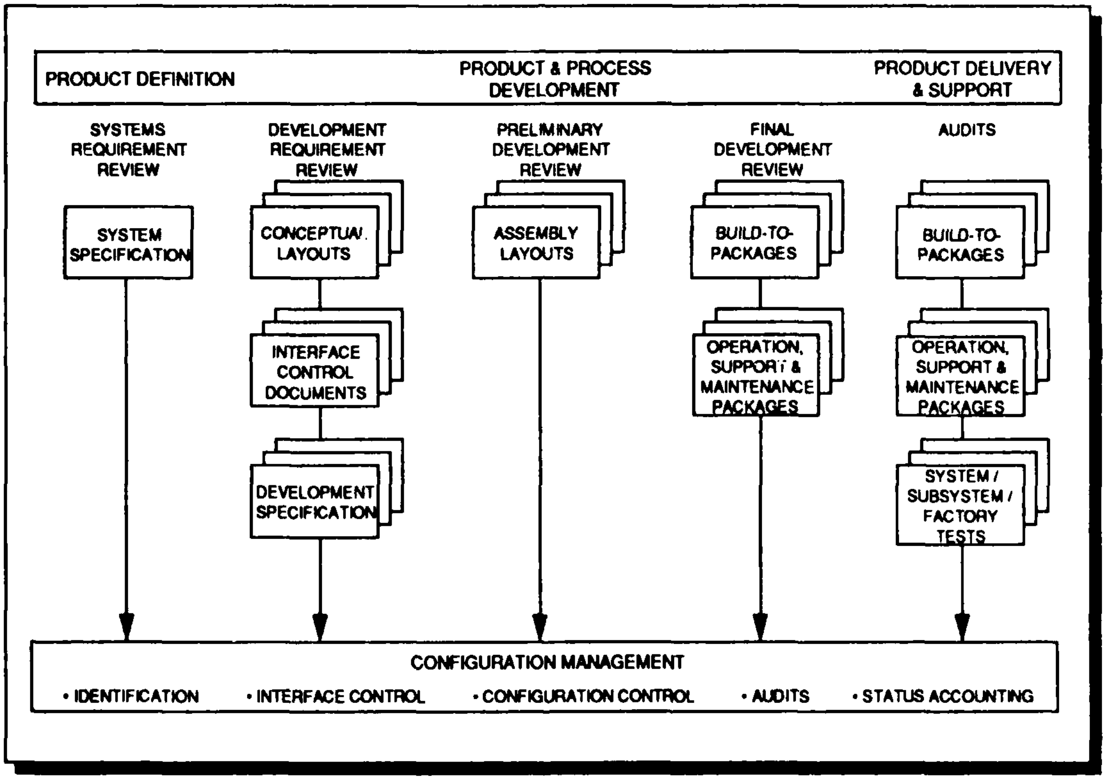

Figure 6

5.0 CONFIGURATION MANAGEMENT

Configuration Management supports the systems engineering management process and ensures the integrity and continuity of the product and process designs throughout their life cycle. This process involves the functions of identification, interface control, configuration control, audits and status accounting as shown in figure 6. Baseline management is one of the more important elements of this process. These baselines should be the product of the integrated technical reviews and audits. Under integrated product development, layouts are used to enhance product definition. For example, the use of automated design tools has made the assembly layout the cornerstone of the detailed design, design analysis, computer integrated manufacturing and computer aided support. As such, the conceptual layouts and the assembly layouts will be subject to configuration management rules. A description of the layout process is contained in the section on Integrated Product Development. This section also describes the Build-To-Package and Operations, Maintenance and Support Package contents which will also be subject to configuration management rules. These packages contain all the information necessary to build, operate and support the product. These packages often contain electronic products and go well beyond the traditional DOD-STD-100 drawings.

Integrated product development requires control of product and process configuration at all levels, not just for drawings as it is done today. Increased interactions of many disciplines with the product definition and product and process development activities and the use of common data bases contributes to this need. Product data must be managed to ensure all personnel are working with the latest applicable data. This includes the means for change notification to inform users of data when revisions are made. Providing common access to product definition data brings with it the responsibility to find data and manage that data including versioning data at the part level as well as capturing specific part or subcomponent attributes. For these reasons, contractors must have a different kind of configuration management system than they had in the past.

Integrated product development requires early baselining of the system and development specifications and interface controls with supporting layouts while deferring government approval of Build-To-Packages and Operations, Maintenance and Support Packages until completion of the final audit of these documents. The government is responsible for the requirements while the contractor is responsible for generating the data to assist in the trade-offs needed to reach a balanced, affordable set of requirements. The contractor is responsible for the design with government assistance in helping to select alternative designs that meet the requirements. This provides for both government and contractor clear accountability in design. It provides for up-front mutual agreement on the requirements stated in performance terms at the system and major subsystem level and the tasks, accomplishments and success criteria for achieving them. Only after successful completion of these agreements will the Build-To-Packages and Operations, Maintenance and Support Packages be subject to government control thus eliminating premature approval of product specifications as may be the case under the current process.

These are just a few of the features required of the contractor's configuration management system in the IPD environment.

6.0 INFORMATION TECHNOLOGIES

6.1 Information Integration Technologies

The concept of integrated product development deals with the interaction among different weapon system development specialists who are responsible for their own specific functional area, but who also work together as a team to make the trade offs which contribute to the best possible product. Given the complexity of the end product, the vast number of decisions which must be made and the large organizations responsible for these decisions, computer systems are widely used to support the development process. In the last three or four years, dramatic improvements have been demonstrated in the application of computer aided design (CAD), computer aided manufacturing (CAM), database software systems and workstation technology in selected engineering, manufacturing and support areas. These technologies have excellent potential to support the implementation of the integrated product development approach in Air Force weapon systems acquisition and the technology development for weapon systems. For example, new modeling techniques based on the use of CAD systems with increased mathematical completeness and accuracy have increased the ability to visualize assemblies at the design stage, including the sequencing of components during assembly and the potential interferences of mating parts. For machined parts, verification of machinability can be determined by the animation/simulation of cutter path travel using the solid modeling capabilities of CAD systems. Reliability and Maintainability (R&M) Computer Aided Design (RAMCAD) application packages now permit a more rapid analysis and modification of the design to better support R&M. These kinds of techniques increase the ability of design, manufacturing and support engineers to interact on an analytical basis early in the design phase. Use of the electronic model can highlight the needed changes before commitments are finalized and thereby reduce or potentially eliminate the amount of expensive change required to the physical part during development. In the management support (text) area, software systems have become more user friendly and responsive to the need for information through the use of relational data bases and other advanced data base techniques. Increased computer power at the mainframe level and the proliferation of relatively low cost, yet powerful workstations have greatly increased the computer power available to the average aerospace engineer.

The significantly improved visualization capabilities and accuracies from specially modified CAD systems have resulted in more reliance on electronic development fixtures which take the place of physical mock-ups. Rapid prototyping through the use of solid modelers, rule based systems and other design, manufacturing and support techniques such as stereolithography are becoming more commonplace. Aerospace companies have recognized these technologies as significant enablers that help to implement integrated product development and thereby increase design, manufacturing and support interaction and efficiency. Early involvement and review of this capability with the program office, users and AFLC could significantly enhance early dialogue and agreement on design rules and analysis techniques. Accurate three dimensional modeling capabilities (although computationally intense) and the transmittal of electronic CAD files across different computer systems within a company (and across different contractors) have demonstrated the actual construction and assembly of development components with a minimum of interference and rework. Some companies are realizing a part fit of over 80% on first time articles without modification and actual time to completion is 40% less than estimated. These capabilities were first demonstrated on the large mainframe computers found within aerospace. Similar ca-

pabilities are now becoming more commonplace on relatively inexpensive workstation systems and, given the competition which exists in this marketplace, significant increases in workstation capability are expected in the near term. The use of this technology has great potential for cost savings if effectively used across the board by contractors (prime and subs) and the Air Force in the development of weapon systems. ASD, in their program management and technical oversight role should consider information integration from three perspectives: (1) To encourage and allow the contractors to move toward the use of integrated systems and thereby become more efficient, (2) To internally use selected amounts of information and supporting computer technology in an integrated way to accomplish the program management and technical oversight role and to interface with the contractor, users and AFLC in a more efficient manner, and (3) To provide AFLC with more appropriate, accurate and timely information for their use.

6.2 Opportunities/Challenges/Issues

There are many challenges to the implementation of an integrated information management strategy in support of Integrated Product Development. Examples of these challenges are:

• Data Security. These issues involve Government access to proprietary contractor data, including concerns over an invasion of privacy and the potential exposure of sensitive information to competitors. These issues can also involve data security and the ability to keep "hackers" from gaining access to the information.

• Configuration Management in weapon system development can take an innovative approach based on the management of an electronic data set instead of engineering drawings. Major improvements are possible. The process definition will be concurrently evolved at the same time as the product definition, most likely in an highly iterative manner. Configuration management techniques must also be applied to the data base(s) that contain the product and process definition. Cultural changes are required to make these changes.

• Technical Data Management can transition from paper intensive processes to digital data delivery and access. There is a need for a common understanding between the Air Force, prime contractors, subcontractors and vendors on what information is required to carry out the integrated development process, when it should be delivered, in what form and how it should be formatted and transmitted. This includes a need for a better understanding, within ASD integrated product development teams of what information different functional members (on multifunctional teams) need to do their job. There is a need to develop an overall information architecture or framework.

6.3 Role of Computer-Aided Acquisition and Logistics Support (CALS)

CALS is a DOD and Industry strategy to enable, and to accelerate, the integration of digital technical information for weapon system acquisition, design, manufacture, and support. CALS is intended to provide for an effective transition from current paper-intensive weapon system life cycle processes to the efficient use of digital information technology. The objectives of CALS as stated in MIL-HDBK-59, "Department of Defense Computer-Aided Acquisition and Logistics Support (CALS) Program Implementation Guide," are:

• To accelerate the integration of design tools such as those for reliability and maintainability into contractor computer-aided design and engi-

neering systems as part of a systematic approach that simultaneously addresses the product and its life cycle manufacturing and support requirements.

• To encourage and accelerate the automation and integration of contractor processes for generating weapon system technical data in digital form.

• To rapidly increase DOD's capabilities to receive, store, distribute, and use weapon system technical data in digital form to improve life cycle maintenance, training, and spare parts reprocurement, and other support processes.

Currently, a variety of automated systems are utilized by weapon system contractors working as a production team to enter, update, manage, and retrieve data from data bases associated with specific acquisition programs. Many of these systems are incompatible with one another as well as with similar systems employed by the government to receive, store, process, and use delivered technical data. The functional capabilities supported by these diverse systems vary greatly. Data created in one functional process is often manually re-entered or re-created in subsequent functional processes, thereby introducing errors and increasing costs.

The near term goals for CALS implementation are attainment of increased levels of interfaced, or integrated, functional capabilities, and specification of requirements for limited government access to contractor technical data bases, or for delivery of technical data to the government in digital form.

These specifications are designed to comply with widely accepted commercial standards developed for these purposes.

The longer term goals of CALS is integration of industry and DOD data bases to share common data in an Integrated Weapon System Data Base (IWSDB) structure that is implemented through Contractor Integrated Technical Information Service (CITIS) and government technical information systems. Data deliverables from, or government access to, specified segments of CITIS data should be required in future contracts and developed in accordance with CALS standards and procedures.

MIL-HDBK-59 provides information and guidance to personnel responsible for the acquisition and use of weapon system technical data. Its purpose is to assist in the transition from paper-intensive processes to digital data delivery and access. It also supports the structuring of contract requirements to achieve integration of various contractor automated capabilities for design, manufacturing, and logistics support.

7.0 INTEGRATED PRODUCT DEVELOPMENT TEAMS

A key feature of successful implementation of integrated product development is the establishment of collocated, multifunctional, empowered, integrated product development teams (IPDTs). Early involvement of all disciplines (design, manufacturing, configuration management, test, logistics, etc.) working as a team to integrated requirements and schedules significantly reduces the rework in design, manufacturing planning, tooling and product support planning. Most important is that equal emphasis of both product and process development is enhanced through the multidisciplined team approach. Key issues in the success of the IPDT approach are organizational structure, human resource development and cultural changes.

7.1 Organization

Successful examples of the Integrated Product Development Process in industry reflect the use of IPDTs. Extending the use of IPDTs within the System Program Offices (SPOs) would enhance the government/industry success through better communications and increased focus on the product and its manufacturing and support processes as opposed to vertical functional requirements. In addition, the use of IPDTs within the SPOs would facilitate the development of integrated requirements, integrated specifications, integrated design processes, integrated planning and scheduling and integrated technical reviews; all of which are keys to successful implementation of the IPD process as discussed early.

The team concept is to have well trained people, organized effectively and empowered to do their job, working with disciplined systems and processes. It is envisioned that the formulation of IPDTs within major SPOs would be formed around the specification tree. Government and contractor IPDTs are organized to achieve the following overall responsibilities:

- Government IPDTs should be organized to develop an integrated properly allocated set of requirements at the performance level, from the weapon system specification down to the lowest indentured specification appropriate for the acquisition.

- Contractor IPDTs should be organized to translate the performance requirements into a definitive set of design requirements and design criteria and transform those into qualified hardware and software products.

- The government and contractor IPDTs interact to assist each other in achieving the weapon system requirements. The contractor IPDTs will evolve design criteria and design solutions to meet the requirements. As the design evolves, further explanation of a requirement or modification to a requirement may be prudent. The government IPDT will review the requirement and the data generated by the contractor IPDT on the alternatives and perform the weapon system technical/cost/schedule trade-offs to ascertain the preferred set of requirements to be chosen. Once selected, the contractor will perform the design, development, test and qualification to the approved specification requirements.

- The government IPDTs interact with the contractor IPDTs during evolution of the design to assist in decisions on design choices that are the purview of the empowered teams. Numerous design selections are required during the process that are fully compliant with the top-level performance requirement, but may very well offer a range of acceptability to the user, support and training communities. In these cases, the government IPDT will review the alternatives with these communities to seek consensus and implement a balanced decision.

To accomplish these responsibilities, four types of teams are envisioned; a management team, integrated product teams, functional teams and special teams.

The management team (figure 7) consists of the program manager and the functional directors. This team would be responsible for the weapon system specification and would provide overall policy, guidance and review of integrated product teams, functional teams and special team activities.

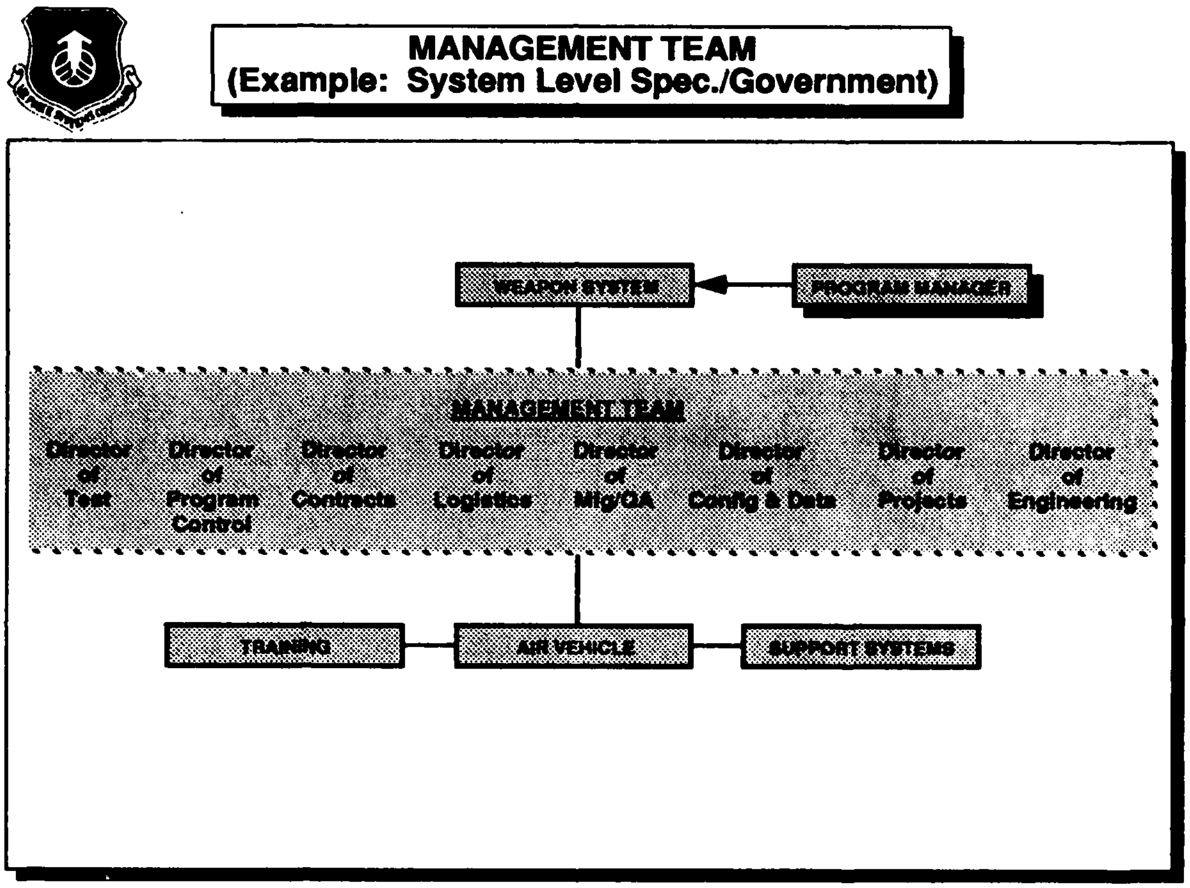

Figure 7

Integrated Product Teams (IPTs) would be structured around the major subsystems of the specification tree. Figure 8 is an example of an integrated product team for a Radar Subsystem.

IPTs should be tailored to each program. Some of the considerations for team formulation are:

• Extent of development and prime contractor/subcontractor relationships.

• Empowered teams should be organized around the product and focused on the development of both the product design and its manufacturing and support processes.

• The prime contractor should be organized utilizing the IPTs or be encouraged to do so.

• Team leaders would normally come from within the multifunctional team. Team leadership may rotate based on the phase of the program. For example, during requirements definition activities, the team leader may come from the projects organization; during development activities, the team leader may be the project engineer; during transition to production activities, the team leader may come from manufacturing; during deployment, the team leader may come from logistics. However, regardless of whomever is designated the overall team leader, the team will have natural leaders responsible for working elements of the project. For example, the natural leader to work a design issue would be the project engineer, a test issue the test engineer, a manufacturing issue the manufacturing team member, a contracts issue the contracts

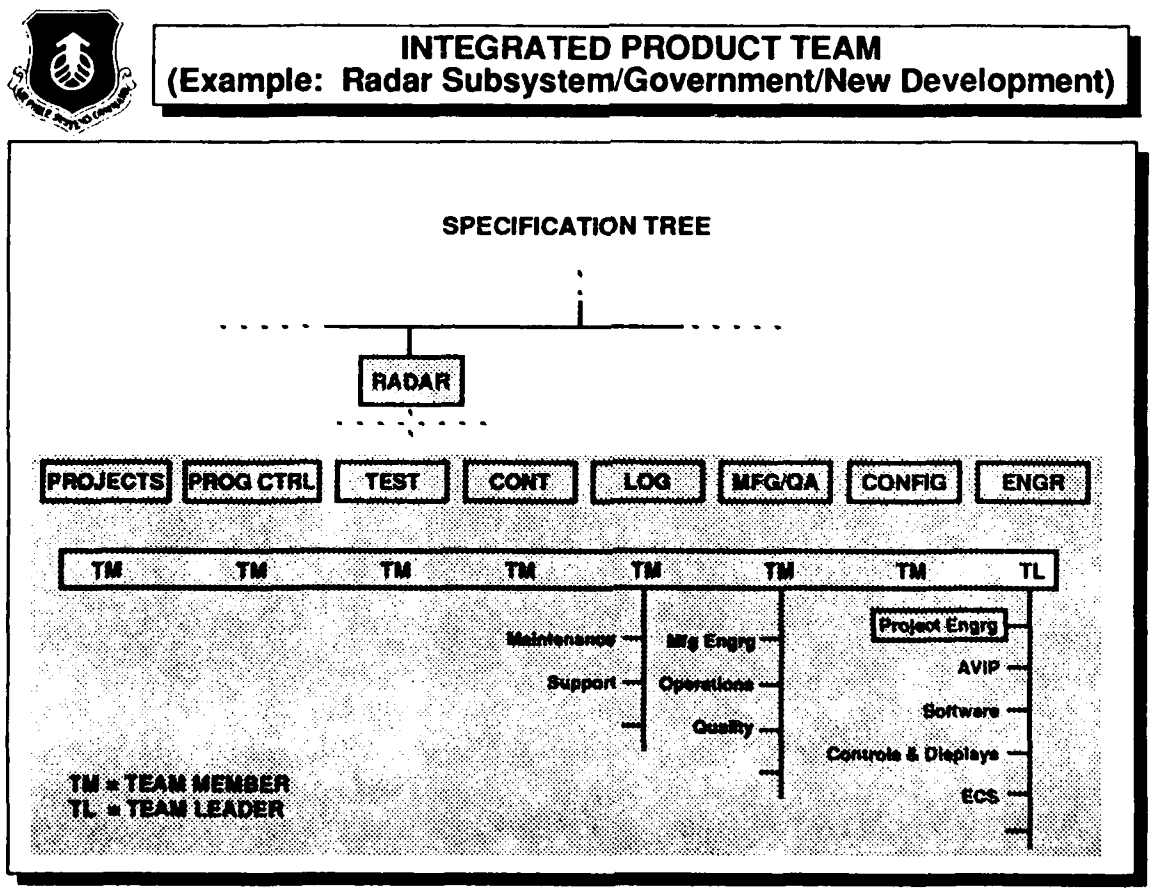

Figure 8

representative. Team oversite would normally be through the management team.

• Team members who spend all their time on one product should be collocated together to facilitate communications and crossfeed of information.

• Team changes should be minimized and the team should remain active through production and initial deployment.

• All extended team support requirements should be identified and a responsible person assigned.

• Team meetings must be attended by all team members and extended team members if their specialty will be addressed during the meeting.

• Team responsibilities and authority should include:

— Participate with "customers" to develop and evaluate requirements.

— Develop and/or approve internal team schedules.

— Review and approve designs and processes.

— Review and/or approve design verification activities and test plans.

— Develop and approve acquisition plans and strategies.

— Member of teams should have appropriate authority to represent his/her functional within the team.

— Act as primary interface with industry on assigned products.

Functional teams will normally be established to develop cohesive strategies to guide and ensure consistent and standard practices across the integrated product teams. They would normally be led by the functional director or division chief to address requirements such as tooling, facilities, or maintenance concepts for the entire weapon system. The SPO functional team should ensure a properly allocated set of performance oriented requirements or constraints at the weapon system level. They will also resolve any issues that impact this policy or these requirements brought to them for resolution by the responsible integrated product teams. Issues may occur as a result of impacts on facilities, test equipment, support equipment or the product design that may require trade-offs and compromises. Through their interfaces with the integrated product teams the functional team will be responsible for ensuring a consistent flow of requirements to the lowest indentured specification appropriate for the acquisition, resolve any issues in implementation that may occur during development, and ensure acceptability of the decision to the users that may be impacted. Figure 9 is an example of a tooling team which would logically be led by a manufacturing organization.

Other special SPO teams may also be established as program office needs dictate. An example of a special team is shown in Figure 10. This example represents a team working the requirements definition for an extensive avionics and structural modification to an aircraft design.

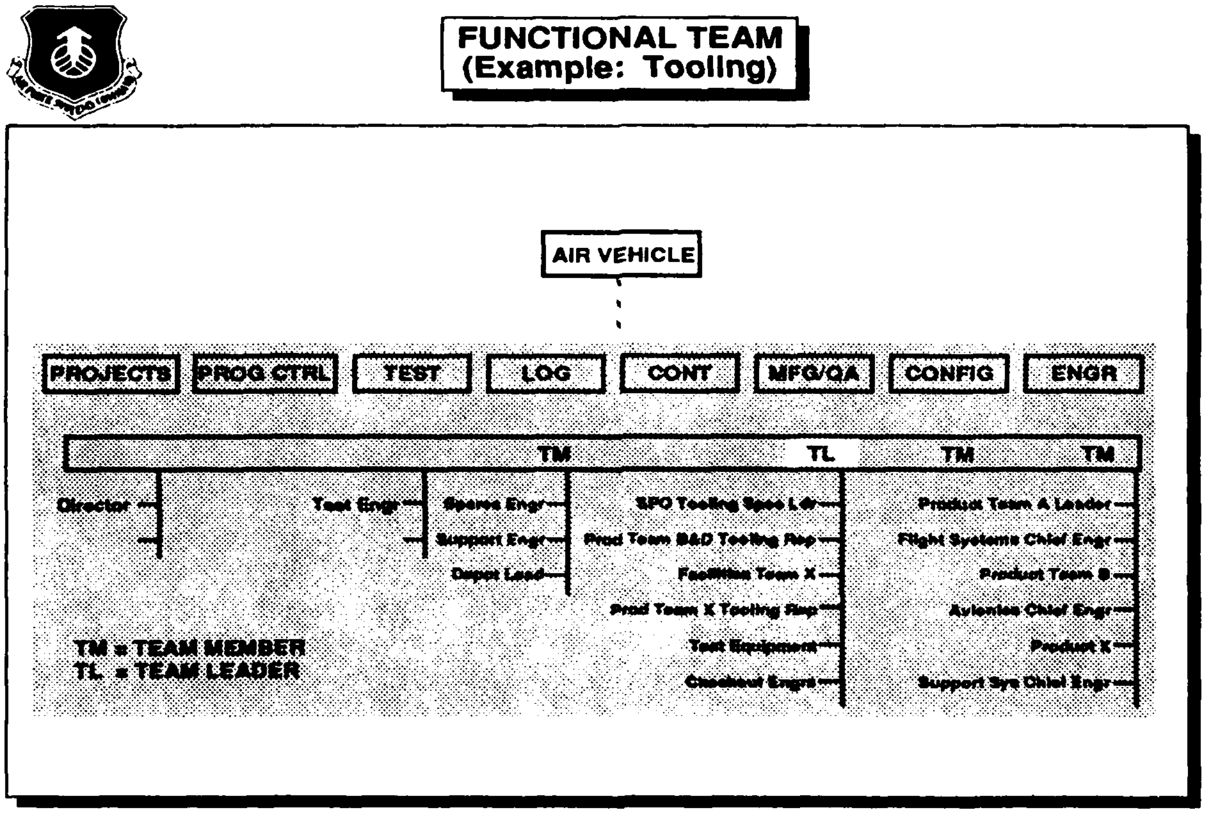

Figure 9

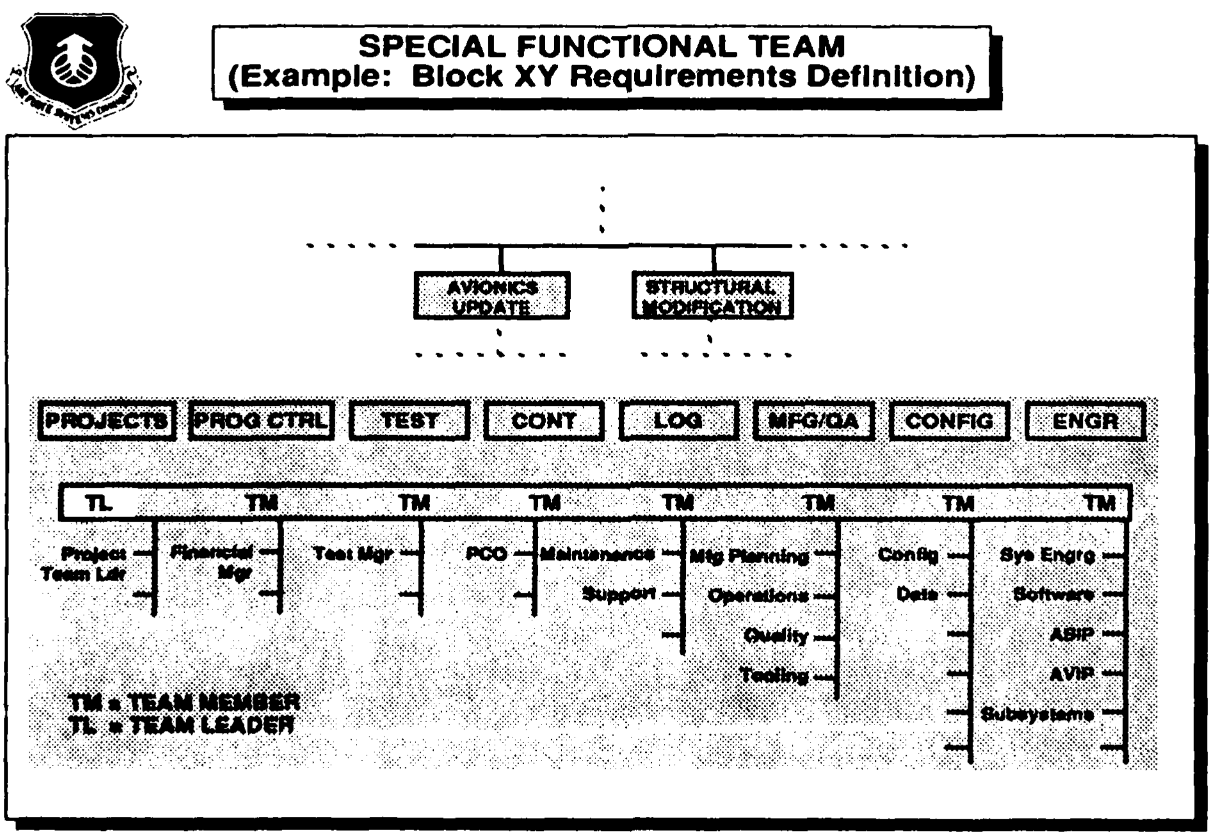

Figure 10

Functional teams also serve a useful function at the ASD "corporate" home office level. For example, to facilitate an on-going linkage of design and manufacturing engineering efforts, standing technical teams dealing with producibility and process control issues may be needed in specialized functional areas such as:

- Composites
- Electronics and Microelectronics
- Materials, Components and Processes
- Metallurgy and Chemical Treatments
- Automation, CAD, CAM, Computer-Integrated Manufacturing

These teams would consist of appropriate design engineers, manufacturing engineers, quality engineers and laboratory representatives. The purpose of such teams would be to integrate design guidance--including design requirements and design criteria to be imposed through the product integrity program specifications, standards and handbooks. They would capture lessons-learned and identify manufacturing technology needs. Such a team would also be in a good position to aid in the transition of proven or emerging manufacturing technology. They would assist integrated product teams in applying the available tools and techniques to address producibility as an integral part of design and development. They would devote the necessary time to problem solving in their specialized area, with corrective action feedback to improve future design or manufacturing techniques. The intent of such integrated functional team effort on the part of the Government activity is to be more effective in the role of technical consultant and advisor to the industry.

7.2 Human Resource Development and Culture Change

The multidisciplined IPDTs create the need for: (1) development of technically qualified people, (2) transforming of functional players into team players, and (3) culture changes in regards to delegation of authority and acceptance of responsibilities. Team members need to be familiar with both the product and its manufacturing, training and support process development and the evolving supporting computer technologies. Systematic training and/or job rotation programs will be required to develop the proper resources. A primary function of the functional staff (matrix home office) will be to develop the integrated policies and practices and train the people that will be assigned to IPDTs. The cultural mind-set of the SPO functional staffs must continue to further evolve from a functional orientation to a product oriented focus in support of the SPO Director and IPDTs. Also, human resource development will be required to train functional players to perform even broader integration roles within the SPO, with the contractor and with the user, logistics and training communities. This must be supported by top management's willingness to change by delegating authority and assigning responsibility to the team members and by creating an environment of trust and cooperation.

Once teams are formed, all team members should receive training in Integrated Product Development principles and team effectiveness techniques.

7.3 Facilities

There is tendency to locate personnel by function which encourages functional orientation to problem solving and presents a significant barrier to continued communications. The integrated product development process requires maximum communications both within the team and with internal and external customers. Where appropriate, physical collocation and use of enhanced electronic communications should be used. Adequate facilities for team meetings is also a requirement.

8.0 INTEGRATED BUSINESS REQUIREMENTS

There are a number of considerations within the integrated product development process which affect our current business requirements and contracting methods. Key processes that need to support IPD are as follows.

8.1 Request for Proposals (RFPs). Industry often organizes in a like manner to its customer—the program office. Industry claims they must do this to communicate and respond effectively to the functional tasking and its corresponding budget. Industry is asked to go one-on-one with their government counterparts and proposals and plans are judged on how the contractor organizes to achieve this interface. Data items are discipline oriented and similar data must usually be reformatted for different government groups. This discipline approach to review and/or approval of data has led to the accusation by industry that the functional disciplines are micromanaging the process rather than allowing contractor creativity in design. RFPs that request contractors to propose based on functional requirements send the message to industry that we want a functional proposal and implementation approaches as opposed to a truly integrated product development approach. Industry has stated that changing the contractual requirements and interfaces is an important facilitator in helping industry to change. Evaluation criteria and Instructions to Offerors must also be structured to encourage a truly integrated proposal and contract.

8.2 Source Selection. Evaluation criteria and source selection evaluation teams must be structured to evaluate integrated proposals and proposed contractual documents. The Source Selection process must be structured to recognize the offeror's unique proposal and the offeror's capability to execute the proposed contract. The offeror's technical approaches may be influenced by the supporting computer technologies that must be understood by the evaluation team. For example, an offeror may propose to use computer mock-up in place of hard mockups. The unique offeror's capabilities must be understood in order to evaluate the proposed technical tasks and schedules. Most-probable cost estimates based on historical data may have questionable relevance to proposals based on a revised development approach using integrated product development. The use multifunctional teams, product-oriented work breakdown structures and advanced computer technology can significantly impact the timing of activities and the nature of tasks to be accomplished.

8.3 Work Breakdown Structures (WBS). The WBS must be carefully structured to support the integrated product team concept. The use of empowered multifunctional teams to develop the product and its manufacturing, support and training capability requires that this work effort and its associated budget be assigned to the team and not to the contractor's functional organizations. This requires a complete definition of the product-oriented WBS element definitions and the ability to tie any nonproduct oriented WBS elements to product WBS elements at the appropriate tier of the specification tree. For example, system level tests would be tied to the system specification and the supporting system level WBS element, where as, subsystem level tests will be tied to the applicable subsystem level specification and supporting subsystem level WBS element. This change is envisioned to significantly change current practices but can be accomplished within current policy and C/SCSC system requirements.

8.4 Funding Profiles and Progress Payment Schedules. The integrated product development process requires multifunctional involve-

ment early in the process thus skewing the traditional funding profile by greater up-front loading of costs. The total program budget should be less but the funding profile will be different. Funding must be made available for inclusion of all necessary disciplines early in the design process. Today's aeronautical equipment development is requiring manufacturing process inventions and development that are often more technically challenging than the product design. Appreciation for this fact and its impact on program schedules and cost must be considered. Progress payment schedules need to be tied in the integrated product development process to the revised products produced by this process. For example, tying progress payment schedules to engineering release, etc. are no longer valid since engineering releases are being replaced by incremental releases of total product definition data. This product definition data may be paper or electronic digital data representing a conceptual layout, an assembly layout, a total Build-To-Package or a Support Package. Progress payment schedules should be linked to the System/Subsystem Integrated Master Schedules and the Technical Review and Audit Process.

8.5 Incentives and Award Fees. Incentive and award fees must be carefully structured to incentivize the objectives of integrated product development. As such, they must be structured to incentivize the quality of the development process. Successful accomplishment of events tied to the revised development process should be given more weight than meeting a calendar schedule.

8.6 Long-Term Supplier Relationships.

Industry is learning that long-term supplier relationships are a win-win situation, providing stability for both partners in the relationship. Short-term agreements that are repetitively competed pressure the supplier to make all his money on a new year contract and force the prime contractor to adjust to working with a succession of different suppliers. Long-term agreements tend to merge the prime contractor and supplier as a team with a common goal, rather than as competitors trying for short-term economic advantages. They provide the supplier with an incentive to maintain quality, as well as the stability required to expand facilities to meet the demand. In some cases, contracts that stretch further out also force the supplier to share the risk/benefit of changes in production rates. The long-term approach also would seem to make it more difficult for new suppliers to come on line, but this does not appear to be the case based on industry experience. In fact, they have reported that competition has become more aggressive with many new companies entering the business and others expanding into new areas.

The commercial airframe manufacturers also are learning the value of staying in close touch with their key suppliers. For example, Boeing has a well-organized team that constantly is taking the pulse of key suppliers and dispatches a task force to help when one gets into trouble. Under Douglas' new approach, they furnish the supplier with its business projection and strategies and provides technical assistance when a company hits a snag rather than switching to a new supplier. Also, contracts do not necessarily go to the lowest bidder; rather, they are awarded on a combination of quality, schedule and cost.

Industry experience with long-term supplier relationships has resulted in more predictable level of quality and on-schedule delivery, while reducing administrative costs associated with re-quoting and re-sourcing work. Getting quality parts on schedule has significantly improved the efficiency of the prime contractors operations. Subcontractors and suppliers are committing to provide a competitive price and are be-

coming more efficient in producing equipment parts and materials. Subcontractors are enjoying their new partnership role of becoming more involved in the design of the parts to maximize production efficiency.

Integrated product development encourages contractors to understand their supplier capabilities and bring their expertise to the development process as early as possible. As such, contractors must select their suppliers prior to having a design or specification. Knowing a supplier's capability requires considerable effort and mutual trust. Industry has been the most successful in accomplishing this by minimizing the number of suppliers and establishing long-term supplier relationships with proven quality suppliers. Manufacturing initiatives such as just-in-time, also significantly impact contractor/supplier relationships.

Integrated business requirements should address competition and breakout policies, multiyear contracts and "best value" contracting approaches. Competition and breakout policies must be prudently tailored to each acquisition so as not to be a barrier and disincentive to industry on establishing long-term supplier relationships while fostering industrial base development. Establishing long-term supplier relationships and resource commitments can be significantly facilitated through multi-year contracts. Contracts and contract administrative practices need to encourage the use of "best value" contracting rather than lowest price.

8.7 Activity-Based Costing. Integrated product development and the practice of continuous improvement requires visibility into "real costs" at the product/process level. A product cost today is often driven by indirect costs that is often over 50% of the total costs. Visibility into these costs is essential to identify major elements of potential non-value added costs. Cost accounting standards that allocate indirect costs do not provide this visibility and may be the source of cost data that can lead to bad decisions. For example, a product that has been "improved" will not reflect the true cost of that product. Industry has reported that they have made "bad" make or buy decisions as a result of the lack of visibility into true costs. The extensive use of computer technology to accomplish design layouts, design analysis, electronic/computer mockup, computer integrated manufacturing and computer integrated support activities and simulation are all contributing to need for Activity Based Costing.

8.8 Cost-Based Profit. Cost-based profit creates a negative incentive for industry to improve his products and processes after contract award. Strategies that minimize this impact need to be investigated and implemented. The proper application of activity-based costing and work measurement techniques can improve visibility into true work content and avoid perpetuating past inefficiencies through cost-based pricing.

9.0 TECHNOLOGY TRANSITION

The concept of Integrated Product Development can be applied both to the weapon system development process and to the technology, prototype and manufacturing process developments which enable weapon system advancements. This includes WRDC advanced development (6.3A) and Manufacturing Technology (7.8) projects, and related contractor CRAD and IR&D efforts. To achieve this objective, process development technology must be considered and funded in a balanced manner with product technology. If this balance can be attained, the opportunity exists to greatly improve the flow of WRDC and related contractor product and process technology to ASD. Four major opportunity areas have been identified.

The first opportunity deals with the initiation of strategic planning for manufacturing processes as early as possible in weapon system concept development. Within the ASD/XR planning process for future weapon systems, and particularly as future advanced product technology requirements are identified, balanced consideration should be given to identifying requirements for manufacturing technology development and the industrial base required to create, manufacture and support these advanced product technology features. Also, in order to better support the XR planning function, improvements in the interface with WRDC must be established to enable early identification of requirements and subsequent program plans for both WRDC product and process technology and manufacturing technology.

A second major area of opportunity is an enhanced approach to integrating WRDC product and process technologies into ASD weapon system acquisitions. To realize improvements in this area requires: (1) Identification of ASD product and process requirements to WRDC on a timely basis, (2) A balanced focus on product and process development in WRDC (6.3A) advanced development projects (including joint projects between MANTECH and 6.3A advanced development), and, (3) Improved interaction between WRDC and ASD, particularly during the early phases of an ASD/XR concept development.

A third major area of opportunity involves complete technology transition criteria. Included in this area are metrics for cost, quality, and producibility and supportability considerations as a big part of the SENTAR process.

A fourth opportunity area involves integrated ASD and contractor planning for CRAD/IR&D to include both product and process development. This area deals with the fact that most CRAD and IR&D projects focus on product technology (unless the CRAD project is funded by MANTECH). A balance between product and process developments in advanced technology projects should be sought by focusing more on the process requirements/developments and manufacturing technology developments required to implement product technology advancements. Overall, closer coupling between future Government weapon system requirements, contractor business objectives, weapon system technology requirements and product and process developments can greatly enhance the payoff from the R&D world. AFLC modification requirements and repair technology developments must also be considered.

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- Mechanical Equipment and Subsystems Integrity Program (MECSIP), MIL-STD-1798
- Software Development Integrity Program (SDIP), MIL-STD-1803

APPENDIX A

LIST OF ACRONYMS

3D/2D	Three Dimensional/Two Dimensional
AFGS	Air Force Guide Specification
AFLC	Air Force Logistics Command
AFSCs	Air Force Speciality Codes
AL	Deputy Chief of Staff for Acquisition Logistics
ALC	Air Logistics Center
ALD	Acquisition Logistics Division
ALH	Directorate of Manpower, Personnel and Training
ASD	Aeronautical Systems Division
ASIP	Aircraft Structural Integrity Program
AVIP	Avionics/Electronics Integrity Program
C/SCSC	Cost/Schedule Control System Criteria
CA	Assistant to the Commander
CAD	Computer-Aided Design
CALS	Computer-Aided Acquisition and Logistics Support
CIs	Configuration Items
CITIS	Contractor Integrated Technical Information Service
CPT	Critical Process Team
CRAD	Contracted Research and Development
D/V	Demonstration/Validation
DB2	Data Base 2
DOD	Department of Defense
DT&E	Development Test and Evaluation
EN	Deputy Chief of Staff for Integrated Engineering and Technical Management
EN(PA)	Assistant for Product Assurance
ENM	Directorate of Manufacturing and Quality
ENSIP	Engine Structural Integrity Program
GD/FWD	General Dynamics Fort Worth Division
GEAE	General Electric Aircraft Engines
IBM	International Business Machines
ILS	Integrated Logistics Support
IOT&E	Initial Operational Test and Evaluation
IPD	Integrated Product Development
IPDT	Integrated Product Development Teams
IPT	Integrated Product Team
IR&D	Independent Research and Development
IWSDB	Integrated Weapon System Data Base
LCC	Life Cycle Cost

LIST OF ACRONYMS (Concluded)

LRIP	Low Rate Initial Production
MANTECH	Manufacturing Technology
MECSIP	Mechanical Equipment and Subsystem Integrity Program
MIL	Military
ML	Manufacturing Technology Directorate
MME	Deputy Chief of Staff for Materiel Management Engineering Division
NAE	National Aerospace Plane Joint Program Office Director of Engine
NSIA	National Security Industrial Association
PC	Personal Computer
PHS&T	Packaging, Handling, Storage and Transportation
PK	Deputy Chief of Staff for Contracting
QFD	Quality Function Deployment
R&M	Reliability and Maintainability
RAMCAD	Reliability and Maintainability Computer-Aided Design
REPTECH	Repair Technology
RFP	Request for Proposal
SDD	Systems Program Office Directorate of Manufacturing and Quality
SDIP	Software Development Integrity Program
SEMS	Systems Engineering Master Schedule
SIMS	System/Subsystem Integrated Master Schedule
SOW	Statement of Work
SPO	System Program Office
TQ	Total Quality
TX	Technology Exploitation Directorate
TXT	Technology Transition Division
WBS	Work Breakdown Structure
WRDC	Wright Research and Development Center
XR	Deputy Chief of Staff for Development Planning

Funding

6.3	Advanced Development
6.4	Engineering Development
7.8	Industrial Base